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The Analysis and Theory Research on the Factor of Multiple Fractures During Hydraulic Fracturing of CBM Wells

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Abstract

The multiple fracture theory is the hydraulic fracturing frontier theory, especially for the coal the fractures, physical and mechanical properties of which is different from homogeneous sandstone. The study of multiple fracture theory is difficult and faces many problems. According to coal rock mechanics and structural characteristics and based on the analysis of stress field of coal near by the hydraulic fracture, The results of the theory study shown that sub-fracture of tension easily formed in the area near the well and sub-fracture of shear formed in the area far from the well more easily in process of coal fracturing. And the paper revealed the development rule of hydraulic fracture.

Keywords: CBM; hydraulic fracturing; multiple fractures; nature fracture

1. Introduction

At present the main measure of CBM exploration is CBM ground drilling exploration, and the main way of ground exploration includes vertical fracturing Wells, level multiple branching Wells and cavernous underground hydraulic cutting. Because of low permeability seam, most of our coalfield CBM exploration rate is low. Therefore, vertical fracturing well was mostly used to improve the exploration rate. For a long time, the hydraulic fracturing technology of CBM vertical wells has been reference the hydraulic fracturing technology of gas & oil wells, and the selection of technological parameters and the

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calculation of fracture patterns are based on the fracturing theory of oil & gas wells. However, that, the mechanics and structural properties of coal is difference from the conventional sandstone reservoir, makes the CBM exploration not achieve the desired effect. From the 1980s, along with the development of practical hydraulic fracturing and the study, people put forward the multiple fractures theory of gas & oil wells, and they did the specific research on the mechanism and influencing factors of the multiple fractures at the same time. With the adjustment of the energy structure, China is speeding up the CBM exploration. And the multiple fractures theory of CBM well became an important research subject.

2. The particularity of the CBM wells by implementing hydraulic fracturing

The particularity of the CBM wells by implementing hydraulic fracturing includes that mechanics properties predecessors special; The anisotropic properties is obvious; Brittle, brittle and complex fracture which were summarized by predecessors, and it also need to study the obvious structural differences among areas and formations, namely the coal structure is different in different areas, even at different depth in the same formation.

There were some adjacent CBM wells using the same hydraulic fracturing technology, but their gas production was very different. The different broken degree of the coal at different areas or even different parts at the same coal seam was the possible reason.

3. The analysis of the influence on multiple fractures of CBM fracturing wells

Almost every time multiple fractures were found (taking core or digging tunnel) after implementation of hydraulic fracturing technology in the reservoir with natural fractures [1]. And the form of multiple fractures is showed three types as: symmetric type, single-wing type and two-wing asymmetric type (A wing for vertical fracture, the other wing for horizontal fracture) [2]. Then we thought many factors resulted in this phenomenon, but the main one was that there were many weak structures such as natural fractures and weak cement faces.

3.1. The influence on the development of hydraulic fracture by natural fracture

3.1.1. The influence by natural fractural near wellbore

As beginning with fracturing, the ahead fluid was injected into strata. Due to the particularity of coal of which the fracture was developed but the connectivity was poorer, the ahead fluid flowed along multiple natural fractures. When the pressure rose to a certain value that was higher than the minimum fracture pressure of coal and could make multiple natural fractures open in a very short period, and then multiple hydraulic fractures were formed near the wellbore at the same time. The direction and form of these hydraulic fractures were controlled by ground stress and the natural fractures as they grown. Along with the hydraulic fracturing went on, the number and form of these hydraulic fractures changed. And there were only one or some hydraulic fractures remained at last [3].

3.1.2. The influence on the growing hydraulic fracture by natural fractures

While the hydraulic fracture was growing in the coal seam, it was possible that there were some large natural fractures in front of the hydraulic fracture. As the angle between the hydraulic fracture and natural fracture was different, it may make different results such as different direction. Then the surface of the hydraulic fracture was not plane but Complex curved surface. And that was improved in Mian Chen's book *the rock mechanics of petroleum engineering*. Here we simplified the model of the hydraulic fracture form in coal seam, and suppose that the hydraulic fracture the surface of which was perpendicular with the maximum main stress came with one larger natural fracture.

As fracturing in the fractured coal seam, if the growing hydraulic fracture came with one larger natural fracture, there were three possible cases:

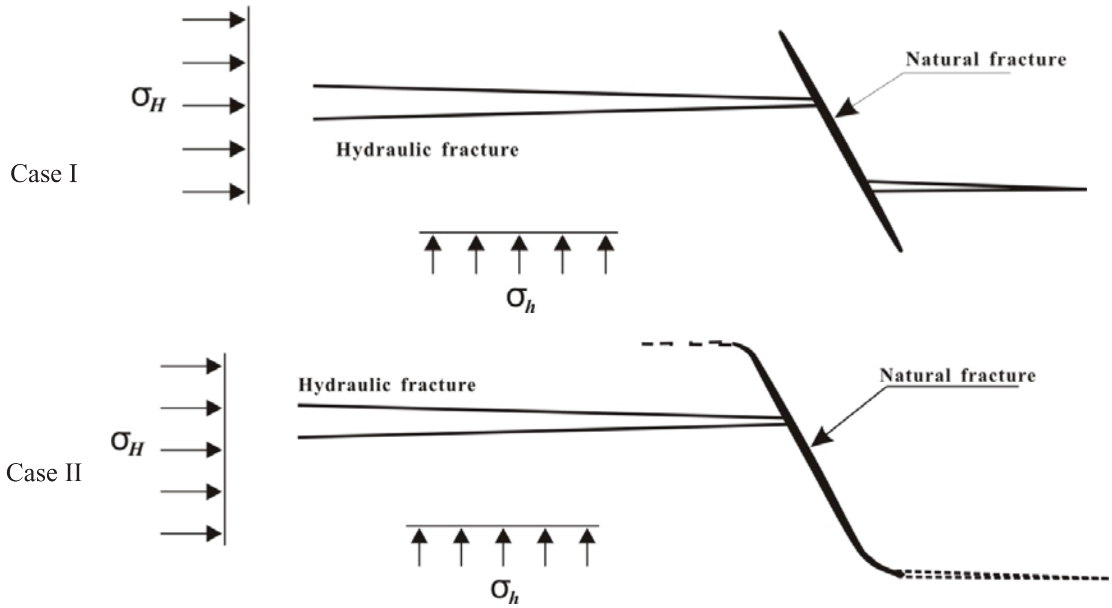

Fig.1.The influence on the growing hydraulic fracture by natural fractures

Case I: The hydraulic fracture through the natural crack directly in the intersection point or breakthrough at the weak point on the surface of the natural fracture (shown as Fig.1-I) and then grown along the direction of maximum main stress. In this case the pressure of the fluid in the fracture couldn't enough make hydraulic fracture break along the natural fracture:

$$P_{break} \le p \le \frac{K_{IC}}{\sqrt{\pi a_1}} + \sigma_n \tag{1}$$

Where: a_1 —the half length of the natural fracture

Case II: After the fracturing fluid flowed into the natural fracture, the natural fracture happens to inflation, and then the hydraulic fracture extended along the natural fracture (one-way or two-way). After that the hydraulic fracture which the direction of was influenced by natural fracture turned to direction of the maximum main stress slowly under the control of the main stress shown as Fig.1-II. At this time:

$$p \ge \frac{K_{IC}}{\sqrt{\pi a_1}} + \sigma_n \tag{2}$$

Case III: The natural fracture was larger and the attenuation of fluid pressure was big. Therefore, after the fracturing fluid flowed into the natural fracture, the pressure was enough to make the natural fracture happen to inflation but not enough to take the hydraulic fracture extend along the natural fracture. Namely the hydraulic fracture was stop at the natural fracture.

$$p \le \frac{K_{IC}}{\sqrt{\pi a_2}} + \sigma_n \tag{3}$$

3.2. The influence on the development of hydraulic fracture by construction parameters

Fig.2.The distribution of sub-hydraulic-fractures

In the process of implementation of hydraulic fracturing in coal seam if the pressure of the fracturing fluid was higher than some value, it was easy to produce sub-fracture in the surface of the main hydraulic fracture that was shown as Fig.2.

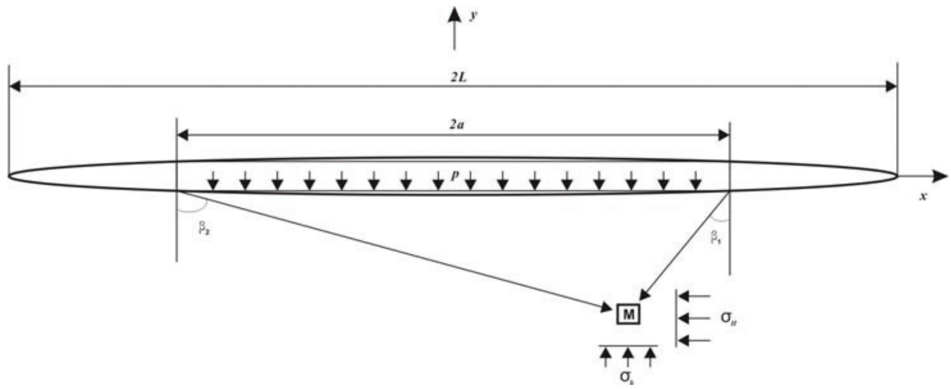

Fig.3.The stress field induced by the vertical hydraulic fracture

Due to the ratio between length and width of the hydraulic fracture was very big and in order to simplify calculation, we regarded as that the pressure was uniformly distributed on a narrow plane which was simplified since the surface of the hydraulic fracture. But the average pressure shown as Fig.3 did not fill the whole crack. Then the value of the stress induced by the pressure of fluid was listed as follow:

$$\sigma_x = \frac{p}{\pi}\left[-\sin(\beta_2-\beta_1)\cos(\beta_2+\beta_1)+(\beta_2-\beta_1)\right] \tag{4}$$

$$\sigma_y = \frac{p}{\pi}\left[\sin\beta_2\cos\beta_2-\sin\beta_1\cos\beta_2+(\beta_2-\beta_1)\right] \tag{5}$$

$$\tau_{xy} = \tau_{yx} = \frac{p}{\pi}\left[\sin^2 \beta_2 - \sin^2 \beta_1\right] \quad (6)$$

Where: p—The pressure uniformly distributed on a narrow plane. And the relationships between the geometric parameters of the above formula were shown as follow:

$$\beta_1 = \arctan\left|\frac{a-x}{y}\right| \quad \beta_2 = \arctan\left|\frac{a+x}{y}\right| \quad (7)$$

When the point M located at the area that was between the two endpoint lines of the equivalent uniformly distributed load, the β_1 in the Formula 3-7 must taken negative. Then we could obtain the total stress including the additional stress produced by the fracturing fluid pressure and the ground stress.

If the equivalent uniformly distributed load the length of which were 40 meters were 9MPa and the maximum/minimum were 14MPa/8MPa, the Fig.4 shows the value of the total stress and the angle of the new maximum main stress at the surface of y=-5.

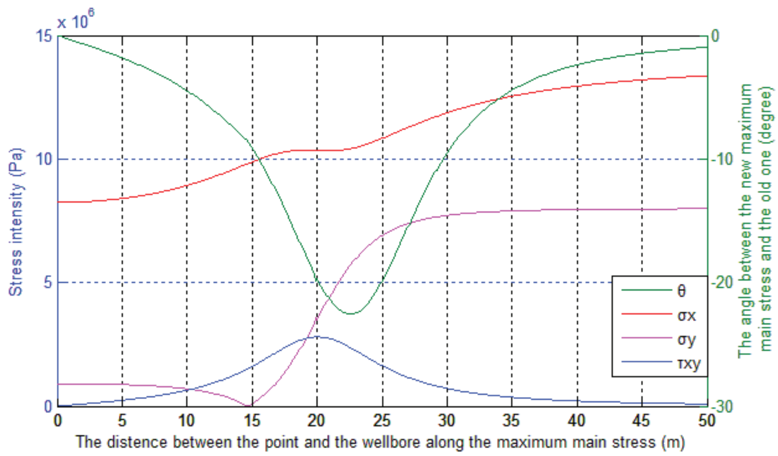

Fig.4.The curves of the stress and the maximum main stress angle induced by hydraulic fracturing

Because of the influence of the fracturing fluid pressure during fracturing, we could find that the stress field was changed a lot from the Fig.4. At the area nearby wellbore, the compressive stress on the direction of the hydraulic fracturing extension was smaller than the fracturing fluid pressure. And if there were some natural fractures in the hydraulic fracturing surface which was not open, the natural fractures was possibly expanded by the fluid pressure and the stress that was perpendicularity to the natural fracture surface. And then it would develop into the sub-hydraulic-fractures. The shear stress which was parallel to the main hydraulic fracture increased with the distance from the wellbore. Then at the area of far from the wellbore if the shear stress was high enough, the unopened natural fracture on the main hydraulic fracture surface was possibly shear ruptured. And then it would develop into the sub-hydraulic-fractures also.

Usually, the fluid pressure near the wellbore within the hydraulic fracture was the highest. Therefore the probability of forming sub-hydraulic-fracture was highest. If the fluid pressure at the area near the wellbore had little difference with the one at the area far from the wellbore, and it was easy to shear break and form the shear rupturing fractures. Especially at the later of the fracturing construction, as the viscosity of the fracturing fluid reduced, once the subprime fractures appeared at the area near the wellbore that could reduce the difference of fluid pressure between the one near wellbore and that far from wellbore, then the probability of forming sub-hydraulic-fracture was increased. And the complex fracture network formed. [4]

3.3. other factors on the influence of the hydraulic fracture

3.3.1. The brittle feature of coal

Owning to the brittle feature of coal, hydraulic fracturing construction made large volume pulverized coal stripped down from the surface of the hydraulic fracture. These pulverized coal that was hydrophobic gathered at the end of the fractures and coursed the resistance of the fluid increased. That made the pressure inside the fracture and the stress on the surface of the fracture rise. When the pressure rises to a certain value which was higher the break value of the coal, it was possibly that the subprime hydraulic fractures formed at the near or far from the wellbore.

3.3.2. The different nature between the coal and surrounding rock

The surrounding rock of the coal was mostly mudstones or shale, and the nature of them was very different from coal. When the pressure inside the fracture was high together with the interface effect between different rocks and the influence of the pulverized coal, it was easy to slip between the coal seam and surrounding rock. Then the horizontal fracture formed between the two seams. So usually the vertical fractures coexisted with horizontal ones. [5]

In addition, we also could control the development of the multiple hydraulic fractures through the artificial construction such as controlling the main fluid pressure or tip screenout fracturing. [4]

4. Conclusion

The technology of hydraulic fracturing in CBM wells was an effective and economical measure of improving CBM production. When we learned from the hydraulic fracturing theory and construction technology of oil & gas well, we must consider the special properties of the coal.

(1) The hydraulic fracturing of CBM well was different from that of the conventional oil & gas well but was similar to that of well in carbonate formation which had many natural fractures. And because the features of the coal were brittleness, high Poisson’s ratio, low elastic modulus and natural fracture, multiple hydraulic fractures were easy to form during the hydraulic fracturing in the CBM well.

(2) When the hydraulic fracture met the natural fracture during CBM well in hydraulic fracturing along with the different fluid pressure at the ends of the hydraulic fracture, it would appear three different results: the hydraulic fracture extended along with the natural fracture and then change the direction under the control of the main stress; the hydraulic fracture broken at the weak point on the surface of the natural fracture and then extended at the direction of the maximum main stress; or the hydraulic fracture stopped at the natural fracture.

(3) After the analysis on the stress of the coal area near the hydraulic fracture, the results shown that during hydraulic fracturing, the tensional subprime hydraulic fractures easily formed at the area near the wellbore and the shear hydraulic fractures easily formed at the area far from the wellbore.

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